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PAPR REDUCTION OF STBC MIMO-OFDM SYSTEMS USING ADAPTIVE ACTIVE CONSTELLATION EXTENSION

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Abstract

In this paper Adaptive Active Constellation (A-ACE) is analyzed for Peak to Average Power Ratio (PAPR) reduction of OFDM Systems with spectral diversity of Space time Block Coding (STBC). To support large system capacity with robustness to multipath fading, OFDM and MIMO have been combined as MIMO-OFDM. To overcome the disadvantage of low clipping ratio problem in clipping based-Active Constellation Extension (CB-ACE) technique for PAPR reduction in OFDM systems, we analyzed ACE algorithm with adaptive clipping control to STBC MIMO-OFDM systems. Simulation results demonstrate that the algorithm can reach the minimum PAPR for severely low clipping ratios, and the performance of this algorithm is superior to the performance of the ACE method in the single antenna OFDM system.

Keywords:
PAPR, CCDF, STBC, MIMO-OFDM, Clipping based-Active Constellation Extension, Adaptive Active Constellation Extension.

I. Introduction

OFDM is a well-known method for transmitting high data rate signals in the frequency selective channels. In OFDM systems, a wide frequency selective radio channel is divided into several narrowband, low-rate and, frequency nonselective sub channels so that multiple symbols can be transmitted in parallel and, the equalization also becomes much simpler [1-3]. The utilization of multiple antennas at both transmitter and the receiver, known as multiple_input multiple_output (MIMO) techniques constitute a cost-effective approach to high-throughput wireless broadband communication systems. In recent years, OFDM combined with MIMO, known as MIMO-OFDM has shown lot of promise in high-data rate wireless broad band applications. Spatial domain increased the diversity gain and/or the system capacity [4, 5], and supports large capacity with robustness to multipath fading. Some of the applications of MIMO-OFDM are Digital subcarrier line (DSL), IEEE 802.11, IEEE 802.16, IEEE 802.15.3a and it is increasingly held that OFDM results in improved downlink performance for fourth generation (4G). Space-time block coding (STBC) technique is a complex combination of coding theory, matrix algebra and signal processing and is mainly designed to combat flat fading channels. STBC can be used to fully take advantage of MIMO-OFDM systems and effectively improve the overall system performance, even on channel with large delay spread. Therefore STBC MIMO-OFDM has been regarded as a promising solution for wireless communication systems.
However, as a result of superposition of many individual subcarriers, OFDM signals have a large peak-to-average power ratio (PAPR). To solve this problem, many algorithms have been proposed. In these algorithms some modifications are applied at the transmitter side to reduce the PAPR [6, 7]. Similarly, MIMO-OFDM also suffers from the drawback of high PAPR on each antenna. The high PAPR leads to the saturation of the high-power amplifiers. Thus, high dynamic range amplifiers degrade performance

also. A number of techniques were proposed to control the PAPR of the transmitted signals in MIMO-OFDM systems, such as clipping [8], modified PTS, SLM, Active Constellation Extension schemes [9-11], and cross-antenna rotation and inversions [12]. An effective technique for PAPR reduction is clipping. However, clipping is a non-linear process and may cause significant in-band distortion, which degrades the BER performance and out-of-band noise, and thus reduces the spectral efficiency. PTS and SLM are probabilistic methods which achieve significant PAPR reduction with only a small data rate loss.

Among various PAPR reduction techniques, the active constellation extension (ACE) technique is attractive for use in the down-link. The reason is that ACE allows the reduction of high-peak signals by extending some modulation constellation points toward the outside of the constellation without any loss of data rate. This advantage, however, comes at the cost of a slight power penalty. For practical implementation, low complexity ACE algorithms based on clipping were proposed in [13, 14]. The basic principle of clipping-based ACE (CB-ACE) algorithms involves switching between the time domain and the frequency domain [15]. Filtering and applying the ACE constraint in the frequency domain, after clipping in the time domain, both require iterative processing to suppress the subsequent regrowth of the peak power. To solve the low clipping ratio problem, a new method of ACE for PAPR reduction has been introduced by combing a clipping-based algorithm with an adaptive clipping control, which allows us to find the optimal clipping level [16]. In [17], the ACE technique has been extended to space-frequency coded OFDM systems to reduce the PAPR. In this paper, it is shown that the space-time coded signals can be represented as the combination of several sub frames. Clipping and filtering are applied to the sub frames. Based on this idea, the ACE method in [16] is extended to STBC case. Simulation results show that this algorithm can achieve the minimum PAR regardless of the low target clipping level. This paper is organized as follows: PAPR properties of OFDM signal are described in Section II. In Section III, we describe the STBC MIMO-OFDM systems. Section IV is devoted to describe and analyze the A-ACE and is compared with the original CB-ACE method for reducing PAPR. In Section V, we present simulation results. Conclusions are given in Section VI.

II. PAPR Properties of OFDM signals

OFDM is performed by taking the inverse discrete Fourier transform (IDFT) of a block of N QAM-modulated data symbols X = [X0, X1, X2,…, XN-1]T, with each symbol modulating the subcarrier from a set of subcarriers. The 'N' subcarriers are chosen to be orthogonal, that is, T is the original data symbol period, and fo=1/T, is the frequency spacing between adjacent subcarriers. The resulting baseband OFDM signal x(t) for N subcarriers can be written as

$$x_n = \frac{1}{\sqrt{ln}} \sum_{k=0}^{N-1} X_k \exp(j\frac{2\pi nk}{lN}), \text{ n = 0,1,2,…, lN-1.} \qquad (1)$$

Where l is the over-sampled factor, which can be achieved by performing an lN-point Inverse Fast Fourier Transform (IFFT) operation to X with (l-1)N zero-padding in its middle. Assume that the symbols Xk are statically independent and identically distributed (i.i.d). Based on the Central limit theorem, when N is large (e.g. N ≥ 64), the real and imaginary parts of xn become Gaussian distributed, each with zero mean and varianceσ^2. Thus, the signal amplitude $|x_n|$ follows Rayleigh distributed, with the PDF as

$$f_{|x_n|}(x) = \frac{2x}{\sigma^2} \exp(-\frac{x^2}{\sigma^2}) \quad x \geq 0.$$

The cumulative distribution function (CDF) of $|x_n|$ can be derived as

$$F_{|x_n|}(x) = Prob\,\{|x_n| \leq x\} = \int_0^x \frac{2y}{\sigma^2} \exp\left(-\frac{y^2}{\sigma^2}\right) dy = 1 - \exp(-\frac{x^2}{\sigma^2}), \ x \geq 0 \qquad (2)$$

where Prob{A} is the probability of the event A. The PAPR of OFDM signal in a given block is defined as the maximum instantaneous power to the average power, i.e,

$$PAPR = \frac{\max\limits_{0 \le n \le lN-1}\{|x_n|^2\}}{E\{|x_n|^2\}} \qquad (3)$$

where E{.} and max{.} denote the mathematical expectation and maximal element function, respectively. Note that PAPR is a random variable.

If the input data power is normalized, then $E\{|x_n|^2\}$ = 1 and we get,

$$PAPR = \max_{0 \le n \le lN-1}\{|x_n|^2\} = 1 \qquad (4)$$

And we get

$$PAPR = \max_{0 \le n \le lN-1}\{|x_n|^2\} \qquad (5)$$

$$PAPR = \max_{0 \le n \le lN-1}\left|\frac{1}{\sqrt{ln}}\sum_{k=0}^{N-1} X_k \exp(j\frac{2\pi nk}{lN})\right|^2 \qquad (6)$$

$$PAPR \le \frac{1}{N}\left|\sum_{k=0}^{N-1} X_k \exp(j\frac{2\pi nk}{lN})\right|^2 \qquad (7)$$

$$PAPR \le N \qquad (8)$$

It clearly shows that the maximum PAPR is equal to the number of subcarriers.

The PAPR reduction capability is statistically measured by the empirical complementary cumulative distributive function (CCDF), which indicates the probability that the PAPR of an OFDM symbol exceeds certain threshold PAPR0, which can be expressed as

CCDF (PAPR(x(n))) = Pr (PAPR(X(n)) > $PAPR_O$) (9)

Due to independence of the N samples, the CCDF of the PAPR of single input single output (SISO) OFDM with Nyquist rate sampling is given by

Pr (PAPR (x(n) > PAPRO)) = 1-(1-e- PAPRo)^N (10)

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated.

III. STBC MIMO-OFDM System

Basic block diagram of the two antenna STBC MIMO-OFDM structure that employs the Alamouti method [6, 7] is shown in figure 1.

The information symbol vector $S = [S_0, S_1, \ldots, S_{N-1}]^T$ is coded into two vectors S1 and S2 by the space-time encoder as

$S1 = [S_0, -S_1^*, \ldots, S_{N-2}, -S_{N-1}^*]^T$, and

$S2 = [S_1, -S_0^*, \ldots, S_{N-1}, -S_{N-2}^*]^T$ (11)

where S* is a complex conjugate of S. The above symbols after IDFT are transmitted concurrently from TX1 and TX2 antennas respectively. The subcarrier-1 transmits S0 from Tx1 and S1 from Tx2, and the subcarrier-2 transmits –S1* from Tx1 and S0*from Tx2. The process of the STBC encoder and decoder can be explained in expressions of even and odd poly-phase components vectors [7].

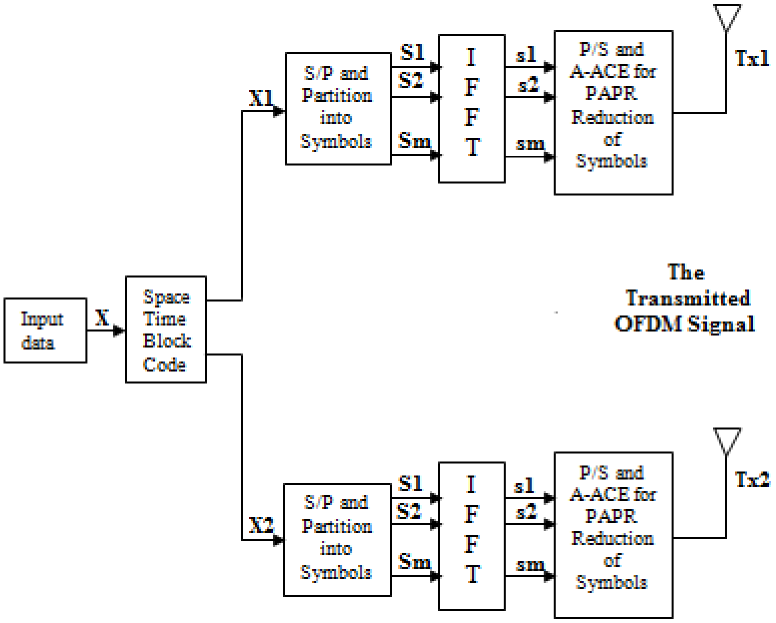

Figure 1. Block diagram of STBC MIMO-OFDM with A-ACE PAPR reduction method

Let $S_{even} = [S_0, S_2, \ldots, S_{N-4}, -S_{N-2}]^T$,

$$S_{odd} = [S_1, S_3, \ldots, S_{N-3}, S_{N-1}]^T \qquad (12)$$

where S_{even} and S_{odd} are lengths N/2 two vectors describing even and odd vectors components of S, the even and odd input components S_1 and S_2 can be described in form of the odd and even vector components as

$$S_{1,even} = S_{even} \quad S_{1,odd} = -S_{odd}^*$$
$$S_{2,even} = S_{odd} \quad S_{2,odd} = S_{even}^* \qquad (13)$$

Hence, the equivalent STBC transmission matrix is written as

$$G = \begin{bmatrix} S_{even} & S_{odd} \\ -S_{odd}^* & S_{even}^* \end{bmatrix} \qquad (14)$$

The STBC MIMO-OFDM communication provides two different gains of Spatial and Frequency [7], thus this communication is suitable to overcome the fading channels. However, this system also suffers from large PAPR due to characteristics of multi-carrier communication OFDM employed on each antenna.

The CCDF of the PAPR of the MIMO-OFDM signals at each transmit antenna is written as

$$PAPR_{MIMO-OFDM} = \max_{0 \le i \le lN-1} PAPR_i \qquad (15)$$

Where $PAPR_i$denotes the PAPR at the i^{th} transmit antenna. This can be further derived as

$$PAPR\ (PAPR_{MIMO-OFDM} > PAPR_0) = 1 - (1 - e^{PAPR_0})^{M_t N} \qquad (16)$$

From equation (16) the CCDF of the MIMO-OFDM is much lower than in equation (10). PAPR reduction method should be employed for OFDM signal on each antenna.

IV. ADAPTIVE ACTIVE CONSTELLATION EXTENSION ALGORITHM

The key idea of the A-ACE for reducing PAPR value is to control the clipping level and the convergence factor together at each step and thus minimizing the peak power signal. The A-ACE algorithm can be initialized by selecting the parameters namely the target clipping level and the number of iterations, denoted by i. As a startup $i = 2$ and the initial target clipping level is assumed as A. The predetermined clipping ratio, γ and given as

$$\gamma = \frac{A^2}{E\{|S_n|^2\}} \qquad (17)$$

Where γ is target clipping ratio, S_n is oversampled OFDM signal. The clipping of the peak signal results in distortion of the original OFDM signal. The distortion can be considered to be noise that causes unreliable communication between the transmitter and the receiver. The distortion caused by clipping the original OFDM signal is classified in two types

i. In band distortion
ii. Out-of-band distortion

The In-band distortion causes the system performance degradation and cannot be reduced, where as the Out-of-band distortion can be minimized by filtering the clipped signals. The signal after filtering the clipped signal is given by

$$S^{(i+1)} = S^{(i)} + \mu\tilde{c}^{(i)} \qquad (18)$$

Where $\tilde{c}^{(i)}$ is Anti-peak signal at the i^{th} iteration, μ is Convergence factor (i.e., is a positive real step size that determines the convergence speed)

μ can be estimated by using the expression below

$$\mu = \frac{Re[\langle c^{(i)},\tilde{c}^{(i)}\rangle]}{\langle c^{(i)},\tilde{c}^{(i)}\rangle} \qquad (19)$$

where Re defines the real part
$C^{(i)}$ is peak signal above the pre-determined level
$\langle , \rangle$ - Complex inner part.

The anti-peak signal $\tilde{c}^{(i)}$generated for the PAPR reduction at the i^{th} iteration is given by

$$\tilde{c}^{(i)} = T^{(i)}C^{(i)} \qquad (20)$$

Where $T^{(i)}$ Transfer matrix of size jN X jN at the i^{th} iteration and $C^{(i)}$ peak signal above the pre-determined level

The transfer matrix is $T^{(i)} = Q^{\wedge *(i)}Q^{\wedge (i)}$ (21)

Where $Q^{\wedge (i)}$ = Constellation order
$Q^{\wedge *(i)}$= conjugative of Constellation order

The original OFDM signal denoted S_N is to be clipped in order to reduce the peak signals. The clipping signal is given by

$$C_n^{(i)} = \begin{cases} \left(\left|S_n^{(i)}\right| - A\right) e^{j\theta_n}, & S_n^{(i)} > A \\ 0, & S_n^{(i)} \leq A \end{cases} \qquad (22)$$

Where $Cn^{(i)}$ = clipping sample

θ_n = arg $(-S_n^{(i)})$

The clipping level denoted by A for the successive iteration is given by

$$A^{(i+1)} = A^{(i)}\mu^{(i)} + \nabla_A \qquad (23)$$

Where $A^{(i+1)}$ is next iteration level

$A^{(i)}$ is present iteration level
μ is convergence factor
∇_A is Gradient with respect to A given as

$$\nabla_A = \frac{\sum_{n\epsilon i}\left|c_n^{(i+1)}\right|}{N_P} \qquad (25)$$

Where N_P is Number of peak samples larger than A
The PAPR obtained for the signal obtained by (18) shows reduction in the PAPR of the original OFDM signal.

V. SIMULATION RESULTS ANALYSIS

The technique A- ACE, in this paper has been simulated using MATLAB version and the results are presented with analysis on margins for PAPR reduction. Also, the performance of this technique brings out the capability of A-ACE relative to the performance of contemporary technique, Clipping ACE. In this simulation, we use 4-QAM constellation mapping, the number of subcarriers N = 256 in OFDM system.

Figure 2 is the reference CCDF for MIMO-OFDM System without any PAPR reduction methods.

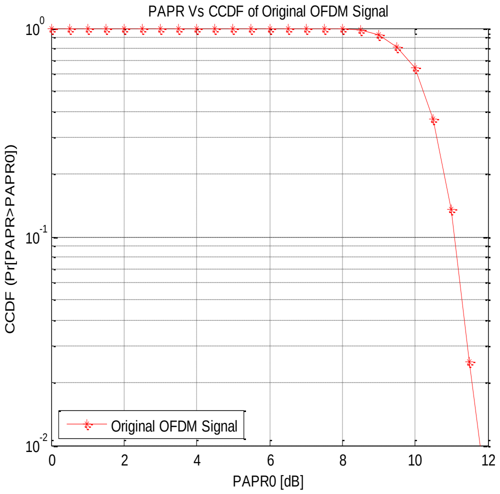

Figure 2. CCDF for MIMO-OFDM System without any PAPR reduction methods.

The CCDF performance can be observed to be that flatness at the CCDF level of 0 dB is almost up to a PAPR of 8.5 dB and then only the reduction begins. This results in lesser control for reducing the PAPR and dictates that reduction techniques have to be incorporated for PAPR, otherwise, heavy saturation results even with slight increase in power due to OFDM carriers. CCDF reaches -20 dB only for higher levels of almost 11.5 db PAPR. Hence uncontrolled OFDM has very small margin to play with, in terms of multi carrier back off in the power amplifier. The effective available back off in this case is only 3 dB.

Figure 3 shows plot of CCDF with PAPR for various clipping ratios using Clipping Based ACE technique.

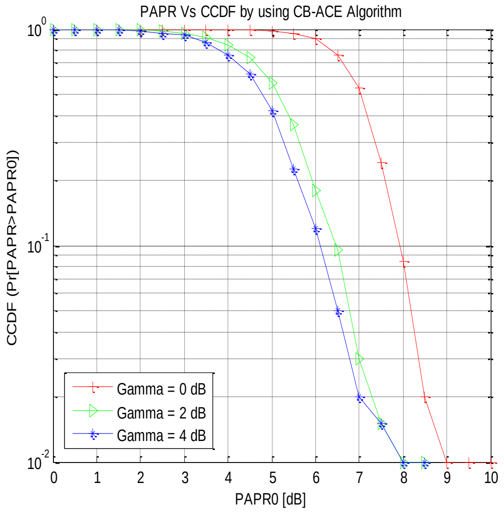

Figure 3. Plot between PAPR and CCDF for different clipping ratios (Gamma) using Clipping Based-ACE method.

The curves in figure 3 are improved vis-à-vis that from OFDM without any reduction methods. Each of the γ values give improved margins. It can be observed that γ of 4 gives the best margin of 5.5 dB (from 2.5 dB to 8 db PAPR) for reduction. Also, the flatness absolute value for all the γ values is at least 2 dB less from the previous CCDFs, which is a better percentage margin in terms of power amplifier performance.

Figure 4 shows plot of CCDF with PAPR for various clipping ratios using Adoptive ACE technique. From figure 4 the reduction margin is remarkably improved to the level of 7.5 dB.

This method enables to have a better OFDM power amplifier performance, in terms of number of carriers at any given phase can be different in numbers because the margin provided is from a very low PAPR value to the threshold higher value of 7.5 dB for a CCDF of -20 dB.

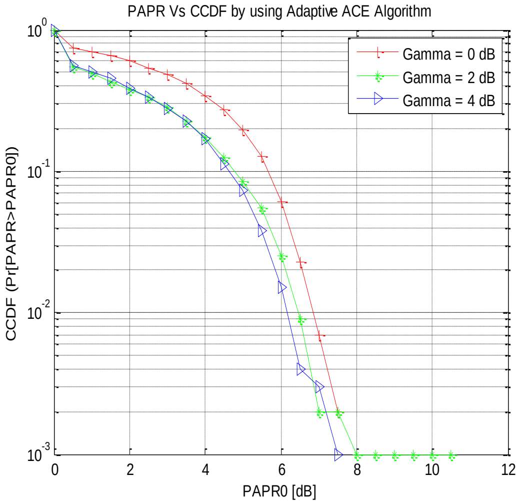

Figure 4 plot between PAPR and CCDF for different clipping ratios (Gamma) using A-ACE method.

These results have more convergence in terms of, different values of γ converge faster except for the small difference in the initial phase near 0 dB. It can be seen that the slopes are almost similar to each of the γ values above this portion.

VI. CONCLUSIONS

In this work we configured the A-ACE method for reducing PAPR to STBC MIMO-OFDM systems. In this method, by control of both the clipping level and convergence factor at each stage, peak power signal is minimized effectively with sufficient margin even at low clipping power levels l. From simulation results, it is observed that this method is an efficient technique to reduce PAPR than clipping only based-ACE method. Although only two transmit/receive antennas are analyzed in this paper, this technique can be easily extended to other systems which use a large number of antennas with added complexity.

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